Cosmic Strips Telescope Simulation with Allpix^2

Report on a work in progress

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Hamburg, May 2022

HELMHOLTZ

DESY.

Cosmic Strips Telescope Simulation with Allpix^2

Agenda

01 The ATLAS ITk Strips System Test
- ATLAS ITk
- System Test

02 ITk Strips Endcap Modules
- Petals

03 Cosmic Muon Flux
- Distribution and East-West Effect

04 The DepositionCosmics module
- The CRY framework
- DepositionCosmics
- Example Usage

05 Current Results
- Tracking Resolution of a Strips Telescope
- Flux Distribution for CRY Particles
- Conclusion & Outlook

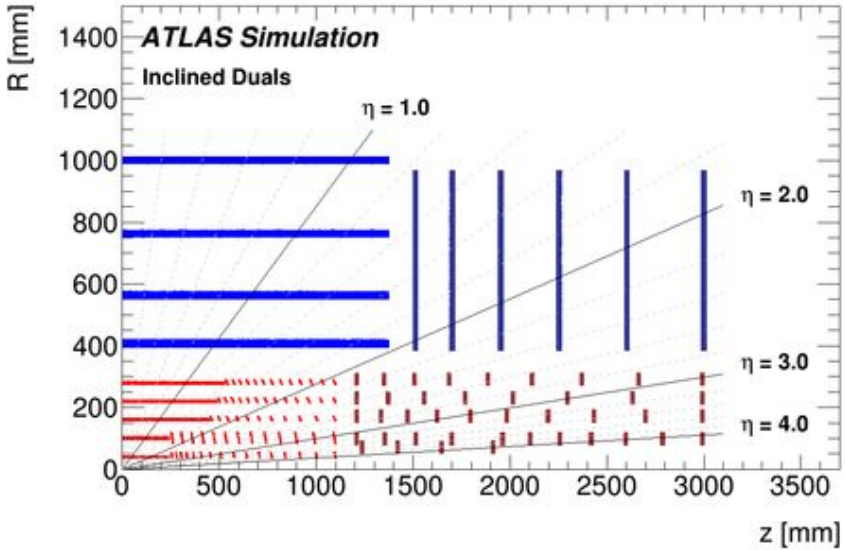
06 Backup Slides

The ATLAS ITk Strips System Test

The ATLAS ITk Strips System Test

ATLAS ITk

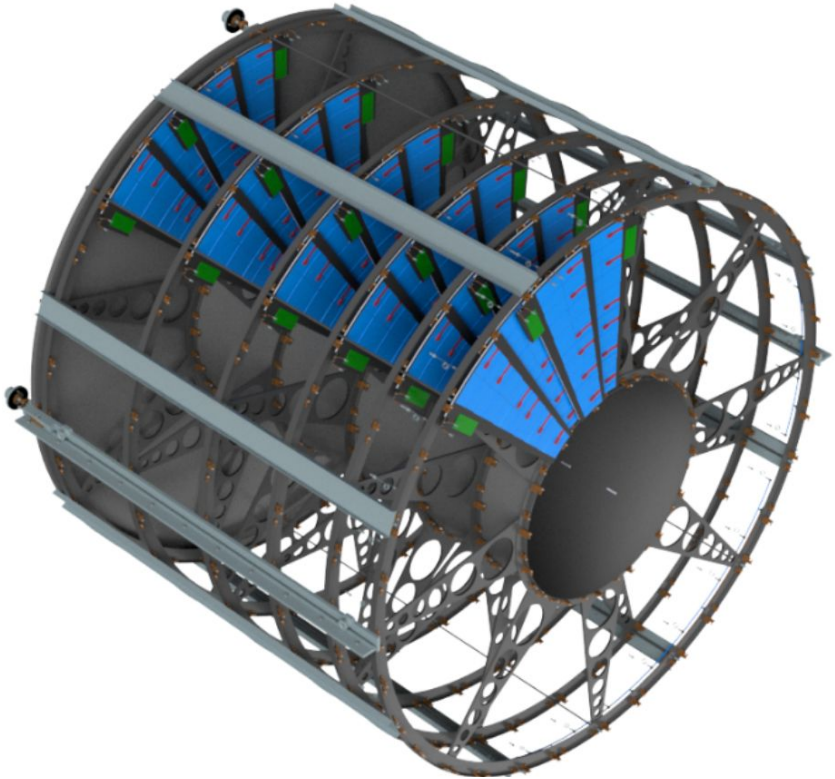
- All silicon tracking detector closest to the interaction point
- A pixel detector measures the tracks close to the initial vertex
- A strip detector is added for more tracking info
- The strip detector consists of a barrel section and two disc-shaped endcap sections



The ATLAS ITk Strips System Test

ITk Strips Endcap

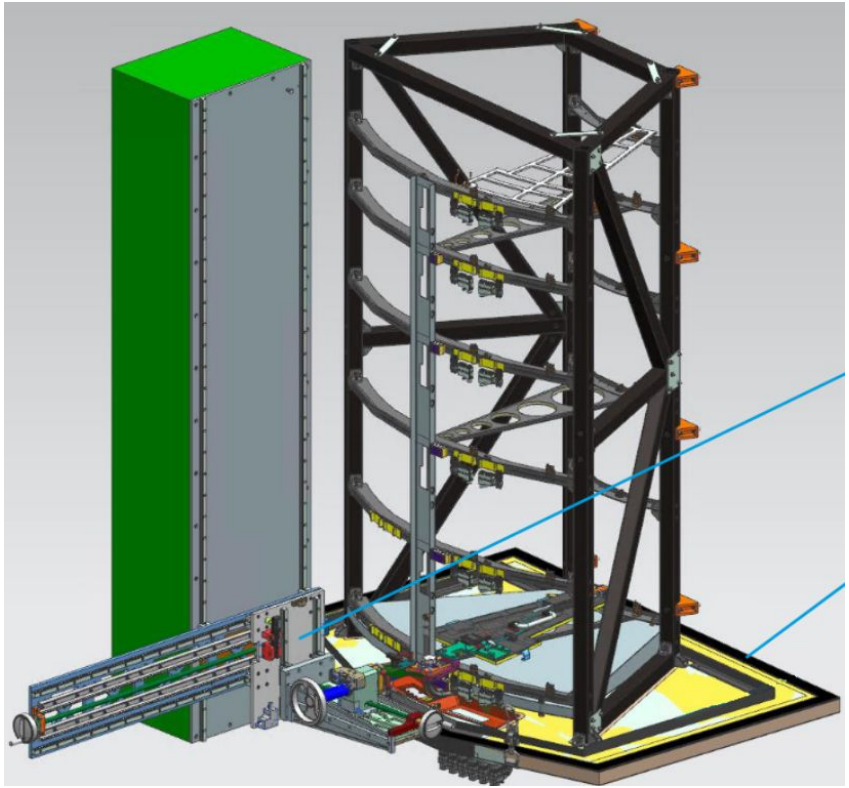
- The endcap consists of six layers of petals
  - Petals are double sided trapezoidal structures with strip modules
- The EC has a carbon fiber mechanical structure, CO_2 cooling and optical fiber readout



The ATLAS ITk Strips System Test

System Test

- The entire setup needs to be tested:
  - Do readout, tracking, cooling, … work?
  - Can we see cosmic muons when taking data?
- We’re building a ⅛ endcap section to do these tests (called the System Test)
- This is currently being built at the DESY DAF (Detector Assembly Facility)

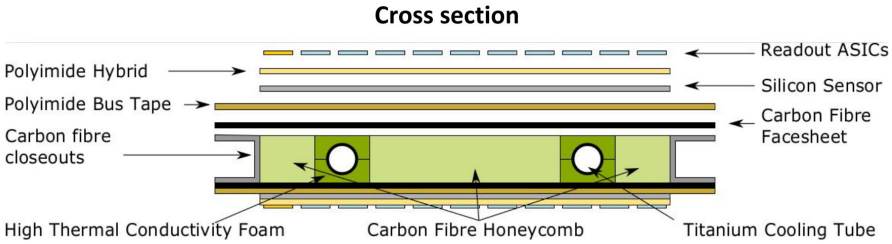


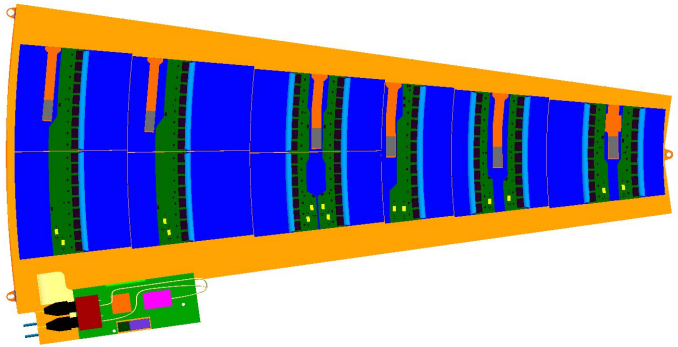
ITk Strips Endcap Modules

ITk Strips Endcap Modules

Petals

- Modules are glued to a carbon fiber structure called “Petal”
- Petals are populated on both sides
  - Due to the stereo angle, this allows for tracking
- The structure also combines electrical links and CO_2 cooling loops



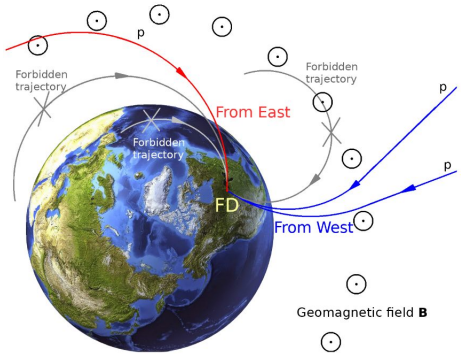


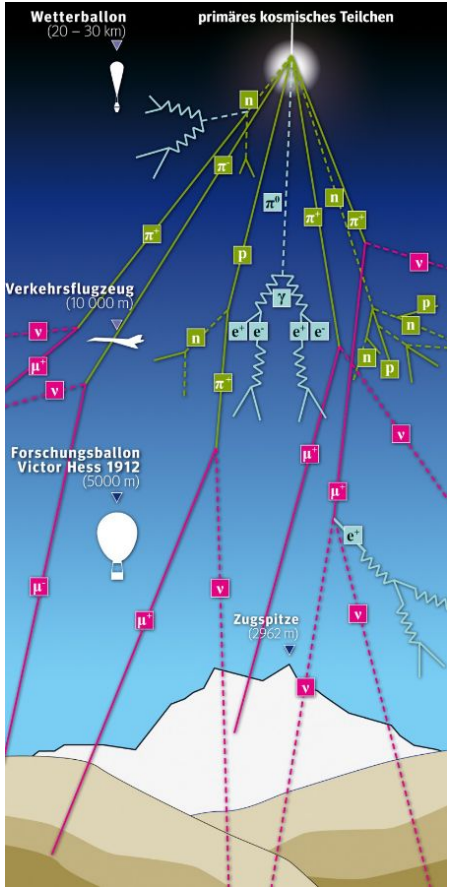
Cosmic Muon Flux

Cosmic Muon Flux

Distribution and East-West Effect

- Cosmic Rays colliding with the atmosphere produce pions, which decay into muons
- Zenith angle dependent flux tends to be $\propto \cos^2\theta$
- Because of earth's magnetic field, there tend to be more muons coming from the west (since cosmic ray particles tend to be positively charged)

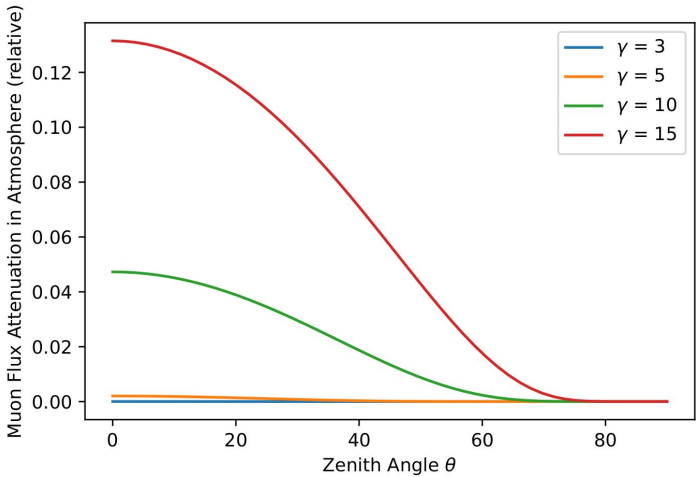


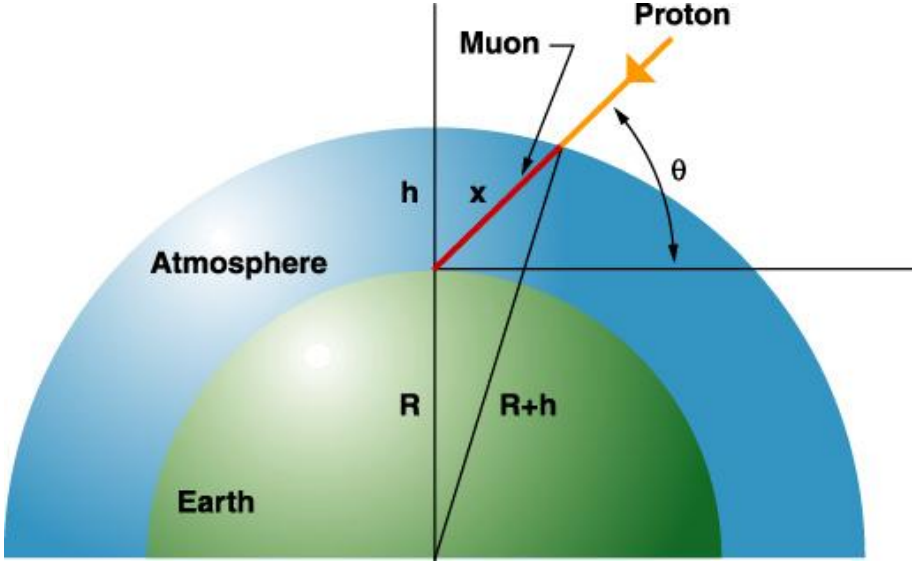


Cosmic Muon Flux

Distribution and East-West Effect

- Travel distance after creation depends on θ
- Some muons won't make it due to their short lifetime (even with time dilation!)





- This introduces a dependence on the muon energy spectrum at creation
- Usually, a $\cos^2\theta$ approximation works fine

Cosmic Muon Flux

Flux Calculation from Track Angles

- Azimuthal and zenith angles are calculated from reconstructed tracks in your detector
- For each bin, the flux is calculated as

$$\Phi = \frac{\partial N}{\partial t \partial A \partial \Omega}$$

where $\Omega = \int_{\varphi_{\text{low}}}^{\varphi_{\text{high}}} \int_{\theta_{\text{low}}}^{\theta_{\text{high}}} \sin(\theta') d\theta' \, d\varphi'$

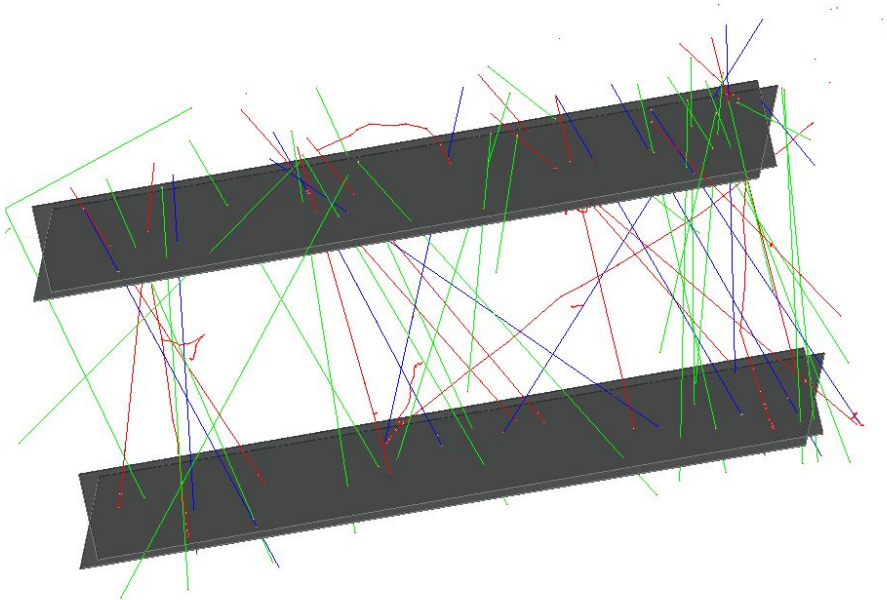
- The effective surface area of the detector has to be found using MC simulations

The DepositionCosmics module

The DepositionCosmics module

The CRY framework

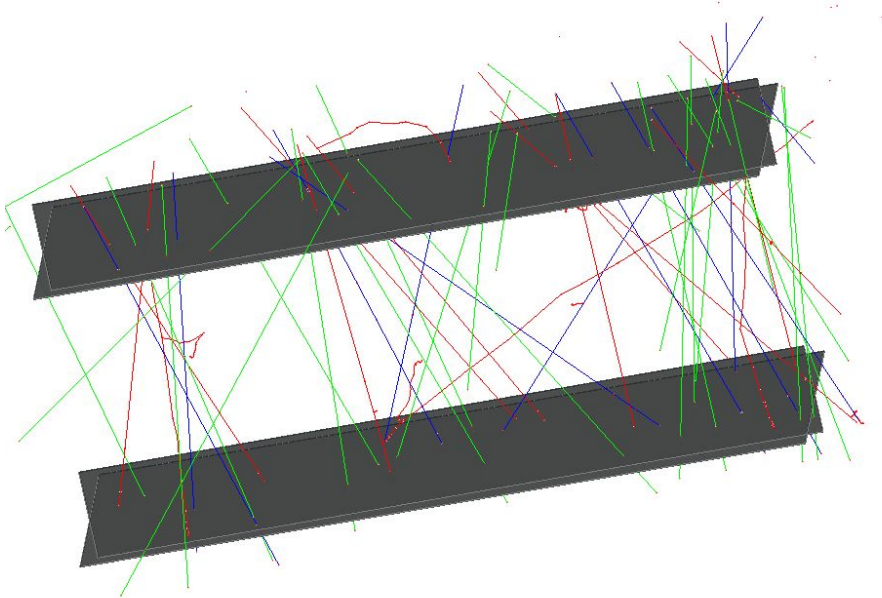
- Generates correlated cosmic-ray particle showers as an input to Geant4
- Uses tables of pre-computed full simulations of CRs that have been checked against data
- Yields a time duration for every event generated



The DepositionCosmics module

DepositionCosmics

- Simon came up with an interface to Allpix Squared
- CRY can now be invoked similar to the DepositionGeant4 module
- Size of the output area is chosen based on the detector size
  - All particles are generated on a square area heading in negative z direction
  - Side lengths 1, 3, 10, 30, 100, and 300 m are available



The DepositionCosmics module

Example Usage

- Usage is similar to DepositionGeant4
- Particles are generated in the xy plane and move in negative z direction
- The total simulation time is printed at the end of the run

Instantiate Module

Types of particles

Data path
(usually not necessary)

```
# Define the cosmic ray source:
[DepositionCosmics]
physics_list = FTFP_BERT_LIV
number_of_particles = 9
max_step_length = 10.0um

return_neutrons = false
return_protons = false
return_gammas = false
return_pions = false
return_kaons = false
return_electrons = false
return_muons = true

data_path = "/afs/desy.de/user/c/cas
```

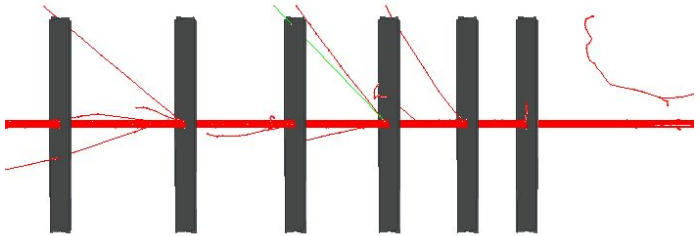
```
|15:30:17.745|  (STATUS) Finished run of 3830 events
|15:30:17.745|  (STATUS) [F:DepositionCosmics] Total simulated time in CRY: 99.3428s
```

Current Results

Current Results

Tracking Resolution of a Strips Telescope

- Use six layers of double strips sensors
  - Geometry inspired by the ITk barrel section
  - 1280 x 28 (400 µm x 24.10 mm) Pixels, 40 mrad stereo angle
- Beam of 10 GeV muons to test the tracking
  - 1.013 tracks per event



Current Results

Tracking Resolution of a Strips Telescope

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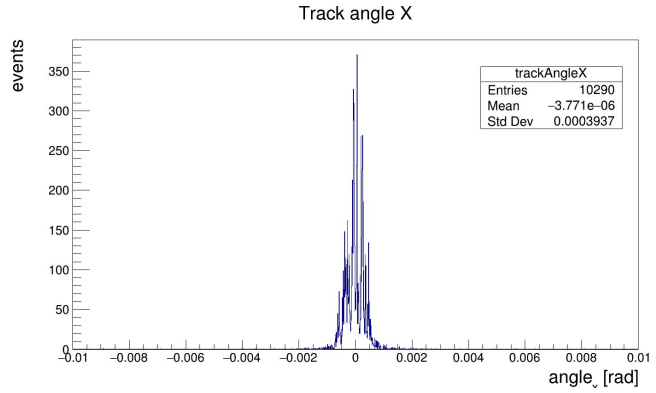
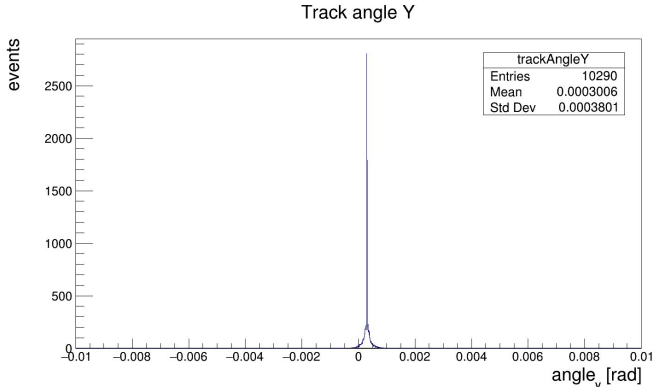
- Beam of 10 GeV muons to test the tracking
  - 1.013 tracks per event
  - Angular resolution in X = 0.4 mrad, in Y = 0.4 mrad (for perpendicular tracks)



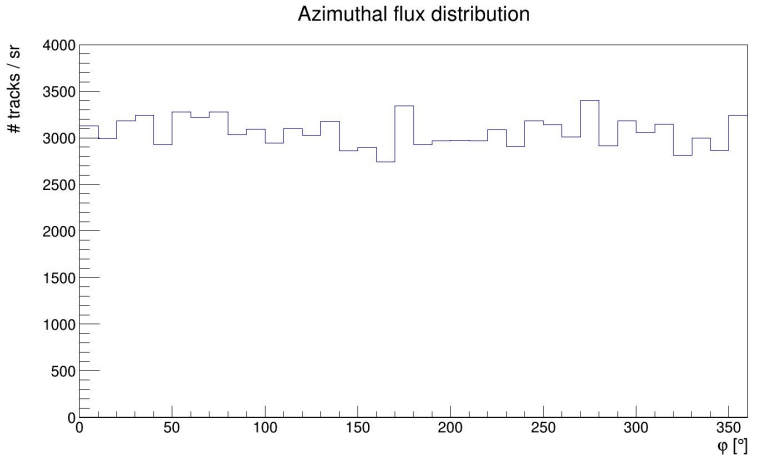


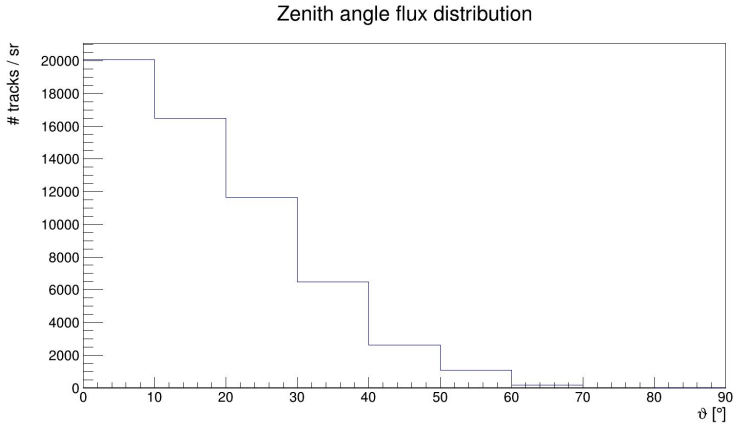
Current Results

Flux Distribution for CRY Particles

- Same geometry as before
- Only generate Muons using CRY
  - Have a 3 m x 3 m x 10 cm concrete wall before the telescope to simulate being in a building
- Zenith and azimuthal fluxes are calculated

$$\Phi = \frac{\partial N}{\partial \Omega}$$





Current Results

Conclusion & Outlook

- We can generate cosmic ray particles in Allpix^2 and get reasonable results
- Simulating regular strip detectors also works
- Next steps:
  - Combine this with Radek's results to get a full system test simulation
  - Normalize the flux to the effective detector area to allow for comparison with other experiments

Thank you

Backup Slides

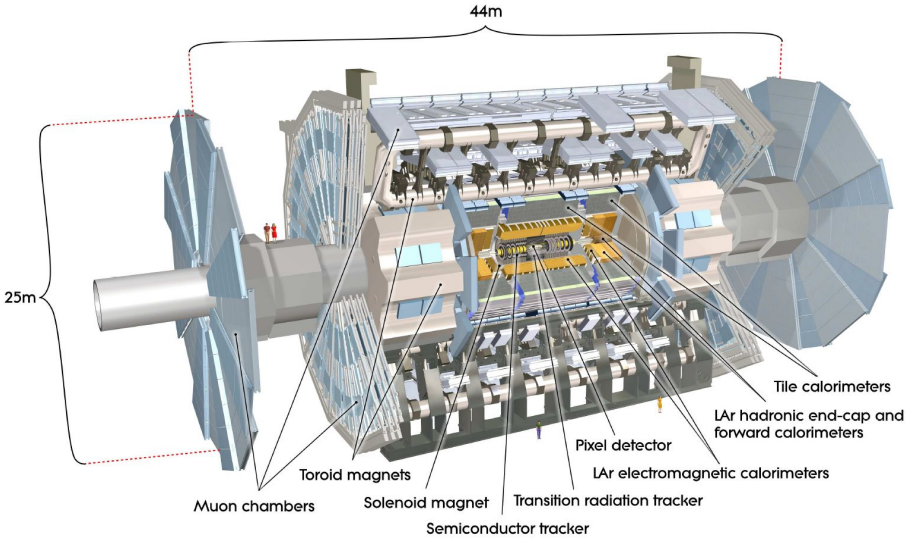
Corryvreckan module: AnalysisParticleFlux

- Histograms:
  - Zenith angle vs. azimuthal angle of tracks and associated 1D histograms
    - Same histograms divided by bin solid angle
  - Zenith and azimuth dependent efficiencies for each detector
    - 2D efficiency map for each detector
- TODO:
  - Implement the calculation of the effective area (need the track angles from MC for this)

Backup Slides

The ATLAS Detector

- Largest experiment at LHC
- General purpose experiment to test (beyond) Standard Model physics
- Due to luminosity upgrades, we're rebuilding most of the detector
- The Inner Detector (ID) is going to be completely replaced

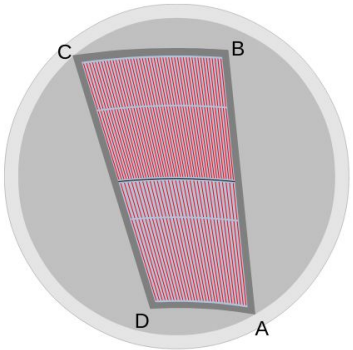


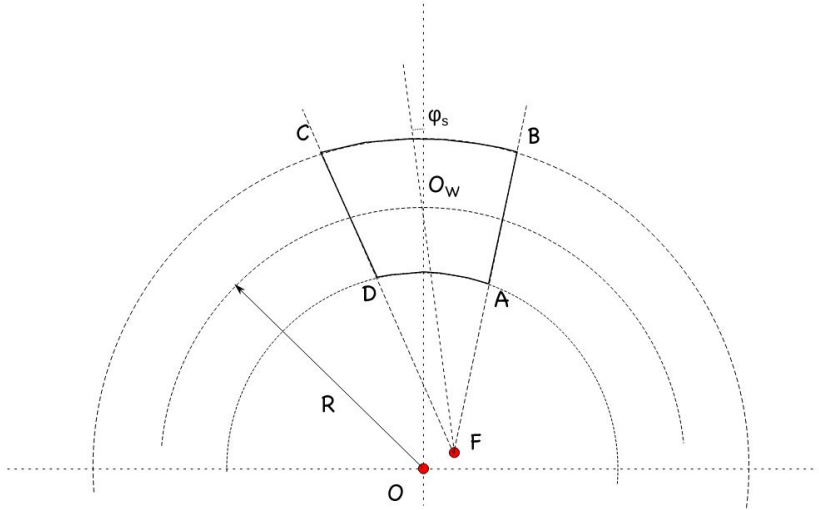
Backup Slides

Geometry and Readout of Endcap Modules

Geometry

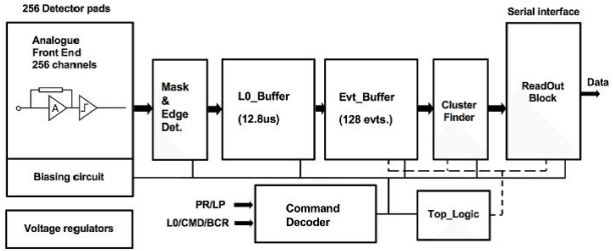
- Rather complex geometry:
  - The strips are oblique with respect to the radii
- The geometry is currently implemented in Allpix by Radek Privara





Readout

- Binary readout via the ABC* chip (glued on top of the sensor)
- Data is collected from all FE chips via the HCC* chip



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